POS511 Cruise Report

R.V. POSEIDON Cruise No.: 511

Dates, Ports: 01.04.2017 (Heraklion) - 22.04.2017 (Heraklion)

Research Subject: The Christiana-Santorini Volcanic Complex

Chief Scientist: PD Dr. Jörg Geldmacher

Number of Scientists: 11

Project: Santorini Evolution

GEOMAR

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POS 511 scientific party. From left to right: Patrik Cuno, Arne Meier, Inken Suck, Theodora Ioannou, Phillip Kosbue, Martin Pieper, Thor Hansteen, Danai Lampridou, Tom Kwasnitschka, Torge Matthiessen, Jörg Geldmacher.

Contents

1. Acknowledgements

We would like to acknowledge Captain Matthias Günther of the RV POSEIDON and his officers and crew for their support, dedication, and professionalism. We thank the Greek Authorities and in particular the Ephorate of Underwater Antiquities from the Greek Ministry of Culture (from which the observer Mrs. Ekaterini Tagonidou has been on board from April 10-13 during day time) for granting us permission to work in their territorial waters. We are indebted to our cooperation partner Prof. Paraskevi Nomikou from the National and Kapodistrian University of Athens for her invaluable scientific advice and administrative and logistical support. Finally, we greatly acknowledge the financial support of GEOMAR, without which this cruise would not have been possible.

2. Introduction (Geldmacher)

The Cristianna-Santorini-Kolumbo (CSK) volcanic field is one of the most violent volcanic systems in the European realm having produced more than a 100 explosive volcanic eruptions within the last 400,000 years with at least four resulting in caldera collapse. The last caldera collapse was caused by the famous Minoan eruption of the late Bronze Age (~3600 BP), which discharged ash over a large area of the eastern Mediterranean and triggered a giant tsunami, which is believed to have contributed to the downfall of the advanced Minoan civilization. Today, Santorini is composed of three islands that are arranged in a dissected ring around the flooded caldera containing two post-caldera islands with active volcanism. The volcanic group of Santorini is located on a NE-SW trending volcano-tectonic zone that also comprises the older Christiana Island group to the SW and the submarine Kolumbo volcanic chain to the NE.

Although the subaerial deposits on Santorini have been studied in great detail, no sampling has been carried out on the submarine portions of Cristiana or Santorini's caldera walls. In order to fully constrain the processes responsible for the initiation and evolution of volcanism in the CSK, the older, submarine history of the volcanism also needs to be included by applying a combination of structural geology with geochemistry, petrology and volcanology as initiated during Expedition POS511. Stratigraphic sampling along selected submarine profiles shall provide a basis for this effort. Therefore, we have conducted photogrammetric surveys and stratigraphically-controlled sampling with the remotely operated vehicle (ROV) PHOCA as well as dredge sampling in the Santorini and Christiana areas during the three week long expedition.

This cruise POS511 is part of a series of three expeditions led by GEOMAR that are conducted in close cooperation with the National and Kapodistrian University of Athens (Prof. P. Nomikou). The previous cruise, POS 510, focused mainly on detailed mapping of the Kolumbo volcanic area by deploying the autonomous underwater vehicle (AUV) ABYSS. During upcoming cruise POS 513 sediment cores will be taken to complete the record of highly explosive eruptions that have occurred in the last 160,000 years. The overarching goal of the three expeditions is to reconstruct the temporal and spatial geochemical and structural evolution of the CSK volcanic field to improve our understanding of this volcanic system and future hazards that may be related to it.

3. Background (Geldmacher, Hansteen, Nomikou)

3.1. The South Aegean active volcanic arc: Geological background

The northern edge of the African plate subducts below the Aegean mircoplate with a velocity of ~4 cm/yr, making the southern Aegean one of the most tectonically active regions of western Eurasia (e.g. McKenzie, 1972; Papazachos et al., 2005). The overriding Aegean microplate consists of thinned and strongly deformed continental crust and is part of the Hellenic (Alpine) orogen. Beginning in Jurassic times, northeast-dipping subduction along the Hellenic arc has resulted in a series of collisions between a variety of lithospheric domains. In the southern Aegean (Cyclades), the upper crust is dominated by metamorphic units like the Cycladic Blueschists, which formed from the Paleocene to the Eocene by the subduction of the Apulian microplate (e.g. Bonneau and Kienast, 1982). Beginning in the Miocene (and still ongoing today, Zhu et al. 2006), the slab retreat and rapid southward migration of the Cretan trench led to widespread extension in the southern and central Aegean region causing crustal thinning, as manifested by shallow Moho depth (~25 km beneath Santorini, Makris, 1977), deep basins (e.g. the Cretan basin) and seismically active faults and graben structures on the Aegean seafloor. Volcanic structures of the active Hellenic Volcanic Arc (HVA) are hosted within extensional neotectonic basins (grabens) crosscutting the Plio-Quaternary sedimentary sequences. The large marginal faults of the basins are generally normal faults but sometimes also accommodate strike–slip movements. The faults serve as pathways facilitating the rise of magmas along the HVA, since the distribution of volcanic centers and the linear alignment of eruptive vents follow these principal orientations (Pe-Piper and Piper, 2005). The HVA stretches from the Saronikos Gulf in the northwest to an area close to the Anatolian coast in the East and includes the active volcanic centers of Methana, Milos, Santorini, and Nisyros (Fig. 1).

The similar distance of all HVA volcanoes to the Benioff zone at ~130 km depth, provides clear evidence for the role of subduction in the genesis of this volcanism (e.g., Papazachos et al., 2005). Accordingly, typical calc-alkaline arc volcanism is present at all volcanic centers, although there is considerable spatial and temporal compositional variation along the arc (Pe Piper and Piper, 2005).

3.2 Age distribution and geochemical signatures of volcanic rocks

The HVA migrated southwards in the early Pliocene to its present position in the South Aegean Sea (Papanikolaou 1993; Royden & Papanikolaou, 2011). Active volcanism of Pliocene age is present at all volcanic centers, except for the CSK, with the earliest volcanic products on Aegina island (part of Methana volcanic center) at the western end of the arc being up to 4.7 Ma old (e.g., Druitt et al., 1999). There is a well-established record of volcanism in the range of 4-2 Ma at the Milos and Nisyros volcanic centers to the west and east of Santorini respectively (see summary in Francalanci et al., 2005).

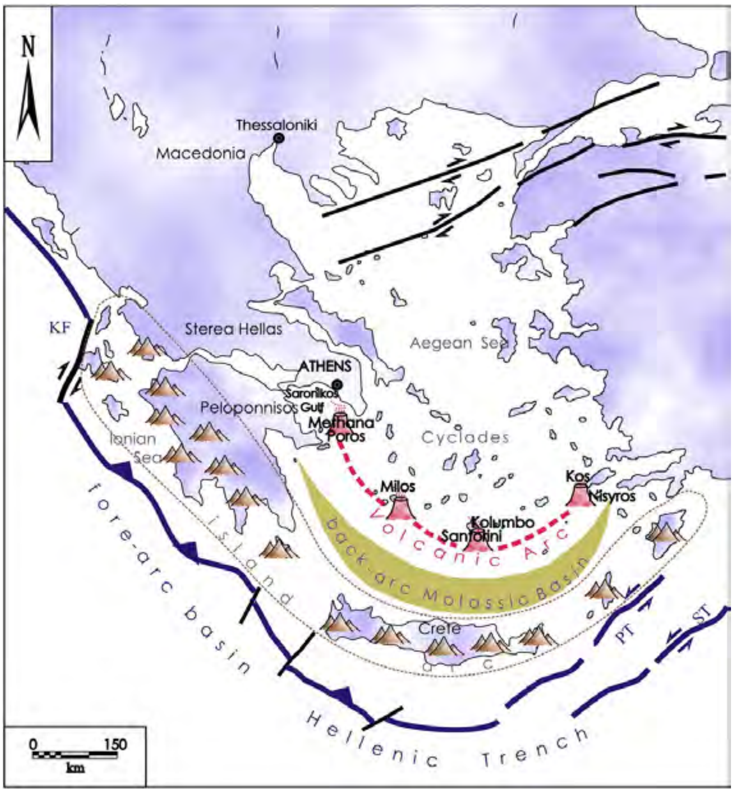


Fig. 1: Geodynamic structure of the Hellenic arc. The African plate subducts along the trench generating (south to north) the Peloponnese-Crete island arc, the Cretan back-arc basin (green) and the South Aegean active volcanic arc. From Nomikou et al. (2012).

The oldest volcanic rocks in the CSK group of islands, located in the central sector of the HVA, consist of early Quaternary submarine tuffs and tuffits at Akrotiri on southwest Thera Island (Santorini). It is unclear if these products were deposited from vents on Thera or from the nearby Christiana volcanic center. All other dated volcanic samples are from subaerially exposed rocks and are younger than 650 ka. The apparent irregular onset of volcanism along the HVA led Francalanci et al. (2005) to assume a systematic correlation of age and geographic distribution of the volcanic centers. However, with no age data from the submarine pedestal of Santorini and Christiana islands, Pliocene activity at the SVC cannot be ruled out. Interestingly, volcanic rocks along the HVA seem to show systematic petrological-geochemical variations with age. According to (Pe-Piper and Piper, 2005), HVA volcanism can be divided in two groups:

1. "Old Western Group", consisting of voluminous, calc-alkaline rocks of mainly andesitic and dacitic composition principally erupted in the Pliocene on Aegina, Poros and in the early Quaternary (or late Pliocene?) at Akrotiri (on Thera), in the Pliocene to mid Quaternary on Milos and in mid to late Quaternary at Methana (still active).
2. "Young Eastern Group", consisting predominantly of mid- to late Quaternary felsic rocks with lesser mafic and intermediate lavas on Milos, Nisyros and (very voluminous) at Santorini and Kos.

Although only limited trace element and isotope data are available, it is evident that the Old Western Group has more enriched isotopic compositions (higher $^{87}Sr/^{86}Sr$

and lower $^{143}Nd/^{144}Nd$) than the Young Eastern Group, reflecting greater amounts of assimilation of enriched continental basement during differentiation of the older group compared to more depleted, asthenosphere-like compositions of the younger volcanic rocks (PePiper and Piper, 2002). Maximum amounts of extension in the Santorini region no doubt allows more mafic magmas to ascend to the surface with less assimilation of the underlying continental basement. A significant role for slab fluids on magma generation is evident from the considerable enrichment in LILE and uranium in late Quarternary Santorini lavas (Zellmer et al., 2000).

3.3. The Christiana-Santorini-Kolumbo volcanic complex and the importance of volcanic hazard mitigation

The CSK complex is located in the central sector of the HVA and comprises three distinct volcanic groups occurring along a NE-SW-oriented fault zone (Nomikou et al., 2013). Christiana with the two islets Askani and Eschati lies at the southwestern end, the Santorini volcanic complex (which includes five islands) occupies the central part, and the submarine Kolumbo Volcano and volcanic chain forms the northeast end (Fig. 2).

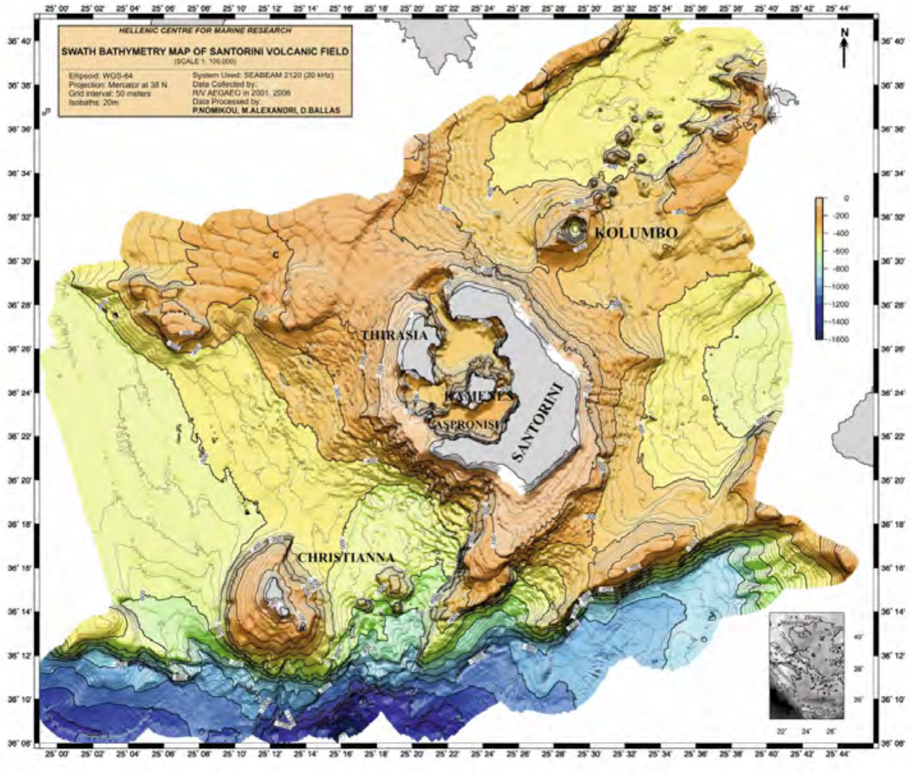


Fig. 2: Swath bathymetric map of Santorini volcanic field using 20 m isobaths (Nomikou et al., 2012a).

The Santorini group consists of a stratovolcano complex with a caldera in its center. The three older islands Thera (also called Santorini), Therasia and Aspronisi are arranged in a dissected ring around the flooded caldera, which contains two post-caldera volcanic edifices making up the Palea Kameni and Nea Kameni Islands. The caldera is a composite structure resulting from at least four collapse events. Prevolcanic basement (Mesozoic carbonates and underlying metamorphic blueschists) crop out in the south of Thera (e.g., Skrapelis et al., 1992). The oldest dated volcanic rocks are submarine tuffs, outcropping near Akrotiri in southwest Thera, which were deposited in the early Quaternary and are speculated to originate from both Christiana and Santorini volcanic complexes (Francalanci et al., 2005). However, no dating has been carried out on any Christiana volcanics so far, but correlations of pyroclastic tuffs on Christiana with ash layers at Akrotiri suggests that Christiana represents the earliest activity in the area. Bathymetric (Nomikou et al., 2013) and tectonic data (Mountrakis et al., 1998) further suggest that the Christiana islets are remnants of a much larger volcano that has been dissected and submerged (Fig. 2). Subaerial volcanism on the Santorini complex began about 650 ka ago on Thera Island (Druitt et al., 1989; Druitt 2014) and volcanic activity continues to the present on Nea Kameni, in the center of the caldera. More than a hundred explosive volcanic eruptions within the last 400,000 years, triggering at least four caldera collapses, make Santorini one of the world's most violent volcanoes (Druitt and Francaviglia, 1992). The last caldera collapse was triggered by the famous Minoan eruption of the late Bronze Age (~3600 BP), which was one of the largest historical eruptions, discharging about 80 km^3 (dense rock equivalent; Jonston et al., 2014) of ash over a large area of the eastern Mediterranean and Turkey. This eruption, which triggered a gigantic tsunami, is believed to have indirectly contributed to the downfall of the advanced Minoan civilization on the island of Crete about 110 km away (e.g., McCoy and Heiken, 2000; Vougioukalakis and Fytikas, 2005; Nomikou et al. 2016). It has also been speculated that the Minoan eruption may be the source of the legend of lost Atlantis or for some of the biblical plagues mentioned in the Book of Exodus. After the Minoan eruption, volcanic activity continued mainly in the intracaldera area where extrusive, effusive and slightly explosive activity built up the Palea and then Nea Kameni islands between 197 BC and 1950 AD (Pyle and Elliott, 2006; Nomikou et al., 2014a). In 726 AD, one particularly explosive event caused considerable destruction on the Santorini islands. Outside Santorini caldera, about 7 km off the northeastern coast of Thera (Fig. 2), the Kolumbo volcano emerged in 1649 AD from the sea and eventually exploded in a paroxysmal event in 1650, which ejected large quantities of volcanic ash and produced a devastating tsunami (Dominey-Howes et al., 2000; Nomikou et al., 2014b). This was the most hazardous and powerful eruption in the Eastern Mediterranean Sea in historic times killing more than 70 people on Thera and causing damage within a 150 km radius (Vougiokalakis and Fytikas, 2005; Ultrova et al., 2016).

Considering the recent seismic unrest and recorded uplift of the Santorini caldera floor in 2011/2012 (Newman et al., 2012; Parks et al., 2012; 2015), a comprehensive knowledge of the CSK volcanic evolution and eruption history is a prerequisite for modern hazard assessment and risk mitigation. Until the beginning of this millennium, however, volcanological/petrological studies in this area were conducted almost exclusively on land (studying subaerially exposed rocks). The (potentially active) submarine volcanic features and submarine bases of the emerged volcanic edifices and caldera walls (containing potentially older geological records) still remain largely unexplored. In 2001 and 2006 high-resolution 20 khz multibeam bathymetric surveys were carried out in the CSK by the Hellenic Centre for Marine Research

(Sigurdsson et al., 2006; Nomikou et al., 2012a; 2013; 2014a). Remotely Operated Vehicle (ROV) investigations (Nomikou et al., 2012b) and manned submersible dives (Camilli et al., 2007; Camilli et al., 2015) were performed on the Santorini caldera floor in 2007 and 2012, respectively (Nomikou et al., 2012a). At Kolumbo volcanic field, ROV dives were first conducted in 2006 discovering active hydrothermal vents and massive sulfide formation (Sigurdsson et al., 2006b) and then in 2010-2011 (Carey et al., 2011; Nomikou et al., 2012a,b; Kilias et al., 2013) and 2013-2014. Although volcanic rock samples were collected during the ROV dives on Kolumbo, systematic, stratigraphically-controlled sampling, potentially allowing for the reconstruction of the older, submarine history of the CSK complex, was not conducted except for a few samples taken from the Kolumbo crater wall (Cantner, Carey and Nomikou, 2014; Klaver et al., 2016). With a permanent population of ~25,000 inhabitants and more than 1,500,000 tourist visiting each year, a comprehensive reconstruction of Santorini's eruption history (by adding the submarine record) is thus of high societal relevance.

3.4 Variation in magma sources in space and time

The age and geochemistry of the CSK volcanism is essential for understanding the temporal and spatial evolution of the volcanism. The composition of deep-seated magmas including their volatile contents are related to source composition, and thus petrological investigations allow us to constrain processes leading up to volcanic unrest (e.g. Wehrmann et al 2014). There is a general lack of submarine samples representing the early stages of the CSK coplex, mainly inside the Santorini caldera and around Christiana. However, the few samples from the submarine, early Quaternary tuffs at Akrotiri are known to possess an "Old Western Group" compositional signature (Pe-Piper and Piper, 2005). It can thus be postulated that Christiana volcanic rocks may also have such geochemical composition. The sampling of the submarine pedestals of Santorini and Christiana conducted during POS511, followed by absolute age dating and geochemical analyses, can provide data for a more complete reconstruction of the igneous history of the CSK area. As younger volcanics on Santorini belong to the “Young Eastern ‘compositional’ Group”, it is also important to investigate the evolution of the postulated mantle sources through time, and thus better constrain the geodynamic processes leading to tapping of the distinct mantle sources. Therefore, we have also sampled the northern, southern and western caldera walls (away from Akrotiri) and (by wax corer) the youngest lava flows from the Kameni vents.

4. Cruise Narrative (Geldmacher)

4.1 Daily Narrative

01.04.2017

Following loading of last equipment, mobilization of the ROV and a successful harbor test, we left the port of Heraklion on 01.04.17 at 8:30 towards our first operational area, Christiana Island. After arriving within 6 nm of Christiana shoreline, we conducted a CTD station (with water sampling) for calibration of the SB3050 multibeam echosounder (CTD-1). The night was spent with multibeam mapping (MB-2) to the east of Christiana Island.

02.04.2017

We started the day by dredging the steep southern flank of Christiana Island (from 700 m up to 500 m water depth) but the dredge returned only mud (DR-3). A repeated deployment (DR-4) further upslope yielded shell fragments and one biogenic rock with shell fragments enclosing a carbonatic matrix containing small (mm-size) volcaniclastic particles. In the afternoon, the ROV PHOCA (with added HR camera) was deployed for a first test dive and photogrammetric survey on the shallow eastern slope of Christiana (ROV-5). Scarps of outcropping hard rock (lava sheets, pyroclastic layers?) were discovered in 400 m depth. During the night we continued the multibeam mapping in the Christiana Island area (MB-6).

03.04.2017

Today all day was dedicated to ROV sampling of Christiana's eastern slope (ROV-7) at the site where the scarps were discovered the day before. 15 samples of *in situ* pyroclastic layers (partly containing large juvenile pumice clasts) were sampled stratigraphically controlled with the manipulator arm of PHOCA. The night was spent mapping the area of the SW opening of the Santorin caldera (MB-8).

04.04.2017

Today's ROV dive (ROV-9) conducted several photogrammetric mapping profiles at the steep north-eastern scarp of Christiana. In the late afternoon a dredge haul was also conducted in the area of the mapping profile tracks but returned empty (DR-10). A CTD station (with water sampling at 100, 75, 50, 25, 10 and 2 m depths) was conducted SE of Thera (CTD-11). The night was spent with mapping the area south of Thera (MB-12).

05.04.2017

This day was allocated for dredging small conical structures ("three seamounts") located halfway between Christiana and Thera's submarine southern pedestal (DR-13, DR-13-2, DR-14 and DR-15). After the first dredge (DR-13) on the westernmost of the three seamounts returned only mud and just one volcanic rock, the dredge haul was repeated at the same location (DR-13-2). Unfortunately, the dredge got stuck right after the start of the haul and could not get freed after repeated efforts. Apparently the weak-link failed to break (and thereby releasing the dredge) and eventually the ship's cable broke off about 5 m above the connection to the dredge resulting in the loss of the equipment. A third haul further east on the same structure returned a piece of freshly severed volcanic lava of apparently evolved chemical composition indicating that this seamount could represent a lava dome (DR-14). A fourth dredge deployment (DR-15) on the southeastern seamount returned only mud. The night was spent with continuing mapping the area south of Thera (MB-16).

06.04.2017

Today, the steep western slope of the large pedestal south of Thera (hitherto believed to represent continental basement, e.g., Kilias et al., 2013) and the slope south of Thera (south of Akrotiri village) were photogrammetrically mapped by the ROV during several dives (ROV-17, ROV-18). Scarps and cliffs of outcropping rocks were commonly observed in the deeper part of the profiles (>300 m) whereas the upper slopes are much more covered by sediments. In the evening a CTD with water sampling (CTD-19) was conducted near the outlet of the caldera (halfway between Aspronisi and the southwestern tip of Thera). The night was spent with mapping the area south and west of Therasia (MB-20).

07.04.2017

The entire day was allocated to stratigraphically-controlled ROV sampling (ROV-21) along the first profile at the western slope of the large pedestal south of Thera (ROV-17 of 06.04.17). In total, 25 samples were collected. Multibeam mapping was supposed to continue during the night but had to be abandoned in the late evening because of a request to take part in a coordinated search for a missing sailor from a nearby passing freight ship. The entire scientific party actively supported the ship's crew in the execution of this task especially during the night.

08.04.2017

After 18 hours, the search operation was called off by the Greek authorities in the late afternoon and scientific operations resumed with the continuation of multibeam mapping in the area east of Thera Island (MB-23).

09.04.2017

Today we continued with our attempt to recover samples from the three seamounts east of Christiana. Two dredge hauls up the southern slope of the westernmost seamount yield only one suitable volcanic rock (DR-24; DR-24(-2)). During a third haul 800 m further east (DR-25) the small barrel dredge got irreversibly stuck and all attempts to free the device failed. Eventually, the weak link broke but the dredge was still stuck. Renewed attempts to free the dredge failed when the security cable eventually broke and the dredge was lost. The night was spent with mapping the area southeast of Thera (MB-26).

10.04.2017

Today and the next three days, we will have guests visiting the ship during the day. After picking up Prof. Nomikou (University of Athens), Mrs. Tagonidou (Ephorate of Underwater Antiquities) and Mr. Stylianopoulos (Diver), who arrived by boat shuttle from Phira, we conducted a ROV dive at the slope beneath the NE tip of Therasia (ROV-27). At that location, a possible archaeological site is assumed and the Greek authorities have asked us to survey that area. Due to the shallow location of this site and the proximity to the shore, the ROV could not reach the shallowest part of this area but focused on the deeper surroundings. In the afternoon, a second survey was conducted at a known hydrothermal vent field nearby (NE caldera). Up to a few meters high mounds covered by bright yellowish bacterial mats were observed and, for the first time at this field, at least one chimney. This short dive was a reconnaissance survey in preparation for an extensive photogrammetric mapping of this vent field that is planned for a later time during this expedition which results shall be combined with high-resolution AUV data conducted during the previous expedition POS 510 (Mark Hannington). After disembarking the day guests, the area NE of Therasi was mapped during the night (MB-29).

11.04.2017
After picking up the day guests Prof. Nomikou (University of Athens), Mrs. Tagonidou (Ephorate of Underwater Antiquities) and two Greek journalists from Kathimerini (one of the largest newspapers in Greece), the ship moved to the southern part of the caldera just off the coast of Akrotiri village. There, the oldest known volcanic successions of Santorini are forming the shoreline and it is safe to assume that any volcanic deposits in the steep submarine cliff below bear an even older age. By recovering these rocks, the temporal, geochemical and volcanological history of Santorini volcanism could be extended back in time. At the toe of the cliff a well-preserved presumed lava flow was discovered with the ROV cameras (ROV-30). While the ROV was starting to try sampling this flow, a leakage of the hydraulic system of the vehicle was detected prompting the immediate abortion of the dive. After the vehicle returned to the ship and was examined, a more serious problem with the hydraulic system was detected. Despite intense efforts, the problem could not be fixed before the evening preventing any further dives during this day. Instead, a CTD station with water sampling (CTD-31) was conducted in the northern caldera (at the hydrothermal vent field examined the day before). The night was spent mapping north of Thera (MB-32).

12.04.2017
After picking up the day guests Prof. Nomikou (University of Athens) and Mrs. Tagonidou (Ephorate of Underwater Antiquities), the ROV dived at the southern caldera wall (just off the coast of Akrotiri) to continue sampling at the same site where the dive was aborted the day before due to the hydraulic problem. Today everything went well (ROV-33) and we sampled 8 very-well preserved lavas and one sedimentary rock (with volcanic components). Due to the heavy sample load, the ROV was brought back on deck at midday (and the sample compartments were emptied) and soon returned back to the seafloor to continue sampling the same slope (at the same depth level) but at a slightly more eastern location (ROV-34). The night was spent with mapping north of Therasia (MB-35).

13.04.2017
Today our day guests, Prof. Nomikou (University of Athens) and Mrs. Tagonidou (Ephorate of Underwater Antiquities), joined us the last time during this expedition. The two ROV sampling dives were conducted SE of Aspronisi at the southern (ROV-36) and northern (ROV-37) flank of a narrow ridge that is assumed to represent a

remnant of the old (pre-minoan) caldera wall. Numerous, predominately well-preserved lava samples were collected. After the disembarkment of our day guests, we left the caldera again to conduct a CTD above the Colombo crater (CTD-38). The night was spent mapping an area east of Thera (MB-39).

14.04.2017

Two ROV dives (ROV-40, ROV-41) were conducted today at the northern caldera wall (off the coast of Cape Perivola). Numerous volcanic samples were recovered. The night was spent mapping east of Thera (MB-42).

15.04.2017

While the propellers of the ROV received urgently needed maintenance on April 15, we deployed the wax corer for the first time during this expedition near the Kameni Islands in the center of the caldera. While previous work focused on studying the sub-aerial exposed Kameni lavas, no attempt has been made to sample the submarine extension of the islands. By encircling the two islands and taking lava (glass) samples with the wax corer from bathymetrically clearly distinct lava flows/lobes, we should be able to correlate the submarine structures with subaerially exposed eruptive centers of known age. By the end of the day we have deployed the wax corer 22 times at 12 different locations (WC-43 to -54). The night was spent with continuing the multibeam mapping east of Thera (MB-55).

16.04.2017

On Easter Sunday, we conducted two ROV dives at the eastern (ROV-56) and western (ROV-57) southern extension of Thera. The objective was to test if this widespread submarine extension of Thera is made up of continental crust or formed by volcanism. Unfortunately, removing in situ samples turned out to be difficult at both locations since all outcropping surfaces were covered by thick carbonate/manganese crusts implying an old age of the rocks. On the other hand, samples of clearly continental crust as exposed on SW Thera (crystalline limestone, blueschists) could not be identified among the recovered 12 samples. More detailed examination of thin sections from these samples, however, will help to answer this question. The night was spent mapping the southeast of Thera (MB-58).

17.04.2017

The aim of the two ROV dives of this day was to finally get volcanic samples from two of the three seamounts located east of Christiana. The first dive was conducted on the southern slope of the westernmost seamount (ROV-59) where dredge haul DR-14 had returned a single small volcanic rock sample that was clearly broken off the basement. As the cameras revealed, all exposed hard surfaces were covered by thick carbonate/manganese crusts implying that these seamounts were not formed by young volcanism (such as exposed in the Santorin caldera) but must be older structures probably related to Christiana volcanism. Unfortunately, all attempts to recover in situ basement rocks failed. Furthermore, the dive operation was hampered by the presence of numerous old, abandoned fishing lines/nets that had to be circumnavigated. Despite all caution, the floats of the ROV wire got eventually entangled in two of these lines. Thanks to the excellent skills of Martin Pieper and his ROV-Team, the wire could be liberated after a short while. A second dive on the summit area of the northernmost seamount (where the bathymeric maps indicated a small crater) found a similar situation: basement rocks were not accessible (ROV-60). The night was spent with further mapping within this area (MB-61).

18.04.2017

Today the ROV dived at the eastern caldera wall and undertook stratigraphically controlled sampling of mainly lavas (ROV-62). Subsequently the remaining time was spent with sampling young lava flows on the caldera floor north of Nea Kameni Island (ROV-63). The sampling yielded many fresh (glassy) lava samples but came to an abrupt end when the power supply of the ROV was suddenly interrupted. After the vehicle was brought back to deck it became clear that a fuse in the high-voltage transformer had blown.

19.04.2017

While the ROV was getting repaired, we deployed the wax corer again as an alternative option for sampling young, glassy lava flows as expected to occur around the two Kameni Islands (WC-64 to -73). The aim was to repeat several stations of our first wax corer deployment on April 15 (although not on the exact same position) at sites where previous sampling was unsuccessful or returned only small amounts of material. The night was spent mapping the area south of the Christiana island group (MB-74).

20.04.2017

In the morning various tests of the repaired ROV were run. Although the ROV and its systems passed these tests, the team discovered a major problem with the power supply of the control container, which had to be fixed. In the meantime, we conducted eleven dredge hauls on the young Kameni lavas (in the caldera) at sites where previous wax corer deployments yielded no or unsatisfactory results (DR-75 to -80). The night was spent with continuing mapping the area south of Christiana (MB-81).

21.04.2017

The last ROV survey with photogrammetric mapping was planned for today in the southern caldera near Akrotiri village. The ROV team worked tirelessly to get the vehicle ready for this last task of the expedition while the ship was positioned on station to be ready immediately. In the early afternoon the ROV started its dive (ROV-82) but, unfortunately, a new electrical power failure forced the abortion of this dive. When it was clear that this problem couldn’t be fixed in the remaining time, we started our transit to Heraklion (Crete).

22.04.2017

With entering the port of Heraklion at 9:00 a.m., expedition POS 511 ended. In total, we have conducted 6 ROV surveys (photogrammetric mapping), 15 ROV sampling dives, 21 dredge hauls, 43 wax corer deployments, 5 CTD stations (with water sampling) and completed 906 nautical miles of multibeam mapping during the night time. In particular the controlled sampling with the manipulator arm of the ROV PHOCA yielded large numbers of well-preserved volcanic samples and made this cruise highly successful.

4.2. Map of deployments

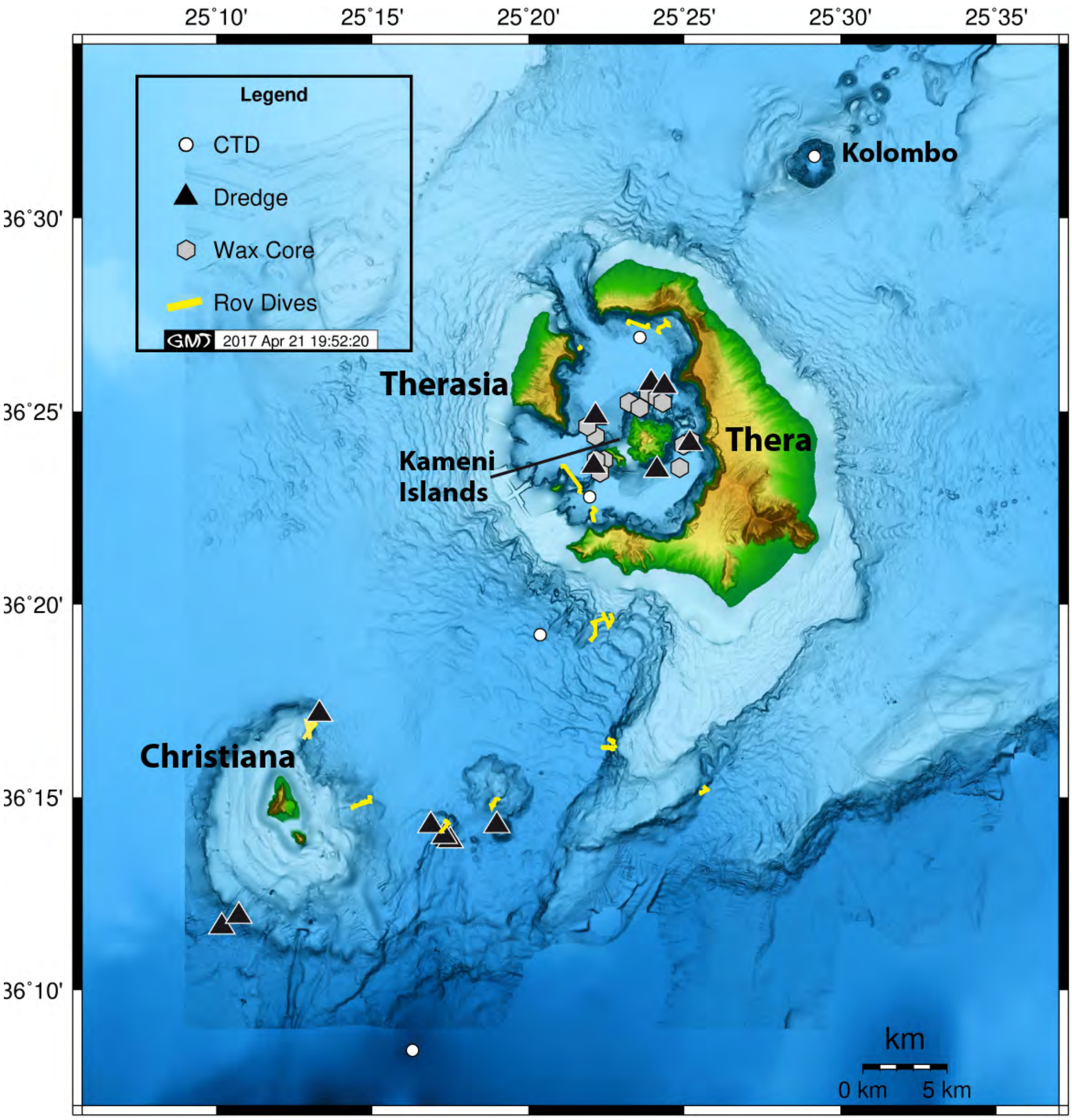


Fig. 3: Map of sampling sites/ instrument deployments during POS 511. Map based on bathymetric data from Hooft et al. (2017-in press) and Nomikou et al. (2013a; 2016b).

4.3. List of stations and scientific activities

Station No.	Date	Latitude (°N)	Longitude (°E)	Equip-ment	Area surveyed / Samples taken/
POS511-1	01.04.17	36°08,42	25°16,03	CTD	Water samples from 5, 10, 25, 50 and 100 m depths
POS511-2	01.-02.04.17	-	-	MB	Mapping Christiana area
POS511-3	02.04.17	36°11,68'	25°10,19'	DR	Slope south of Christiana/ no rock samples (mud)
POS511-4	02.04.17	36°11,92	25°10,27	DR	Slope south of Christiana/ Biogenic fragments (mm-size volcaniclastics)
POS511-5	02.04.17	36°14,98	25°14,96	ROV	Eastern slope of Christiana/only survey
POS511-6	02.-03.04.17	-	-	MB	Continuation of mapping Christiana area
POS511-7	03.04.17	36°14,92	25°14,91	ROV	Eastern slope of Christiana/15 samples from pyroclastic layers
POS511-8	03.-04.04.17	-	-	MB	Mapping SE caldera opening
POS511-9	04.04.17	36°17,19	25°13,26	ROV	Northeastern slope of Christiana/only survey
POS511-10	04.04.17	36°17,16	25°13,32	DR	Northeastern slope of Christiana/ one rock
POS511-11	04.04.17	36°19,20	25°20,40	CTD	Water samples from 100, 75, 50, 25, 10 and 2 m depths
POS511-12	04.-05.04.17	-	-	MB	Mapping south of Thera
POS511-13	05.04.17	36°14,27	25°16,90	DR	Westernmost of three seamounts between Christiana and Thera/ mud and two rocks
POS511-13-2	05.04.17	36°14,26	25°16,88	DR	Westernmost of three seamounts between Christiana and Thera/dredge lost
POS511-14	05.04.17	36°13,91	25°17,38	DR	Westernmost of three seamounts between Christiana and Thera/ one rock
POS511-15	05.04.17	36°14,25	25°18,98	DR	Southern of three seamounts between Christiana and Thera/no rocks (mud)
POS511-16	05.-06.04.17	-	-	MB	Mapping South of Thera

Station No.	Date	Latitude (°N)	Longitude (°E)	Equip-ment	Area surveyed / Samples taken/
POS511-17	06.04.17	36°16,26	25°22,49	ROV	Eastern slope of the large pedestal south of Thera/ only survey
POS511-18	06.04.17	36°19,02	25°22,05	ROV	Southern slope of Thera (south of Akrotiri)/ only survey
POS511-19	06.04.17	36°22,8	25°22,0	CTD	Water samples from 100, 75, 50, 25, 10 and 2 m depths
POS511-20	06.04-07.04.17	-	-	MB	Mapping South and west of Therasia
POS511-21	07.04.17	36°16,27	25°22,11	ROV	Southern slope of Thera (south of Akrotiri)/ 25 samples
POS511-22	07.04.17	-	-	MB	Mapping South and west of Therasia
-	-	-	-		S&R operation
POS511-23	08.04.-09.04.17	-	-	MB	Mapping South and west of Therasia
POS511-24	09.04.17	36°14,02	25°17,29	DR	Southern slope of Seamount east of Christiana/ 10 samples
POS511-24-2	09.04.17	36°14,01	25°17,31	DR	Southern slope of Seamount east of Christiana/ 2 samples
POS511-25	09.04.17	36°13,96	25°17,45	DR	Southern slope of Seamount east of Christiana/ dredge lost
POS511-26	09.04.-10-04.17	-	-	MB	Mapping East of Thera
POS511-27	10.04.17	36°26,62	25°21,67	ROV	NE tip of Therasia/ only survey
POS511-28	10.04.17	36°26,98	25°24,11	ROV	Northern caldera/ only survey
POS511-29	10.04.-11.04.17			MB	Mapping north and east of Therasia
POS511-30	11.04.17	36°22,42	25°22,07	ROV	Northern slope of Akrotiri Peninsular/ no rock samples - dive aborted due to technical failure
POS511-31	11.04.17	36°26,9	25°23,6	CTD	Water samples from 100, 75, 50, 25, 10 and 2 m depths
POS511-32	11.04.-12.04.17	-	-	MB	Mapping north and east of Therasia
POS511-33	12.04.17	36°22,44	25°22,05	ROV	Southern caldera (off Akrotiri coast)/ 9 samples
POS511-34	12.04.17	36°22,20	25°22,07	ROV	Southern caldera (off Akrotiri coast)/ 8 samples

Station No.	Date	Latitude (°N)	Longitude (°E)	Equip-ment	Area surveyed / Samples taken/
POS511-35	12.04.-13.04.17	-	-	MB	Mapping north of Therasia
POS511-36	13.04.17	36°22,84	25°21,71	ROV	Southern caldera (off Akrotiri coast)/ 11 volcanic samples
POS511-37	13.04.17	36°23,55	25°21,15	ROV	Southern caldera (SE of Aspronisi)/ 10 volcanic samples
POS511-38	13.04.17	36°31,58	25°29,17	CTD	Water samples from 100, 75, 50, 25, 10 and 2 m depths
POS511-39	13.04.-14.04.17	-	-	MB	Mapping NE of Thera
POS511-40	14.04.17	36°27,26	25°23,27	ROV	Northern caldera (Cape Perivola)/ 12 samples
POS511-41	14.04.17	36°27,18	25°23,89	ROV	Northern caldera (Cape Perivola)/ one rock sample (hydrothermal crust?) -dive aborted du to technical problems
POS511-42	14.04.-15.04.17	-	-	MB	Mapping east of Thera
POS511-43	15.04.17	36°23,36	25°22,34	WC	Kameni Islands
POS511-43-2	15.04.17	36°23,36	25°22,34	WC	Kameni Islands
POS511-44	15.04.17	36°23,48	25°22,19	WC	Kameni Islands
POS511-45	15.04.17	36°24,37	25°22,15	WC	Kameni Islands
POS511-45-2	15.04.17	36°24,37	25°22,15	WC	Kameni Islands
POS511-46	15.04.17	36°24,60	25°21,93	WC	Kameni Islands
POS511-46-2	15.04.17	36°24,60	25°21,93	WC	Kameni Islands
POS511-46-3	15.04.17	36°24,60	25°21,93	WC	Kameni Islands
POS511-47	15.04.17	36°25,30	25°23,29	WC	Kameni Islands
POS511-47-2	15.04.17	36°25,30	25°23,29	WC	Kameni Islands
POS511-48	15.04.17	36°25,19	25°23,64	WC	Kameni Islands
POS511-48-2	15.04.17	36°25,19	25°23,64	WC	Kameni Islands
POS511-49	15.04.17	36°25,53	25°23,79	WC	Kameni Islands
POS511-49-2	15.04.17	36°25,53	25°23,79	WC	Kameni Islands
POS511-50	15.04.17	36°25,34	25°24,23	WC	Kameni Islands
POS511-50-2	15.04.17	36°25,34	25°24,23	WC	Kameni Islands
POS511-51	15.04.17	36°25,23	25°24,30	WC	Kameni Islands
POS511-51-2	15.04.17	36°25,23	25°24,30	WC	Kameni Islands
POS511-52	15.04.17	36°24,21	25°25,25	WC	Kameni Islands
POS511-52-2	15.04.17	36°24,21	25°25,25	WC	Kameni Islands
POS511-53	15.04.17	36°24,05	25°25,14	WC	Kameni Islands
POS511-54	15.04.17	36°23,55	25°24,83	WC	Kameni Islands
POS511-55	15.04.-16.04.17	-	-	MB	Mapping east of Thera
POS511-56	16.04.17	36°15,17	25°25,69	ROV	Eastern slope of southern extension of Thera/ 8 samples
POS511-57	16.04.17	36°16,49	25°22,72	ROV	Western slope of southern extension of Thera/ 4 samples

Station No.	Date	Latitude (°N)	Longitude (°E)	Equip-ment	Area surveyed / Samples taken/
POS511-58	16.04.-17.04.17	-	-	MB	Mapping southeast of Thera
POS511-59	17.04.17	36°14,40	25°17,40	ROV	Westernmost of the three seamounts east of Christ,/ 3 samples
POS511-60	17.04.17	36°14,84	25°18,87	ROV	Northernmost of the three seamounts east of Christ,/ 10 samples
POS511-61	17.04.-18.04.17	-	-	MB	Mapping east of Christiana
POS511-62	18.04.17	36°24,15	25°25,36	ROV	Eastern caldera/ 15 samples
POS511-63	18.04.17	36°25,04	25°23,22	ROV	North of Nea Kameni/ 9 samples
POS511-64	19.04.17	36°23,36	25°22,34	WC	Kameni Islands
POS511-64-2	19.04.17	36°23,36	25°22,34	WC	Kameni Islands
POS511-64-3	19.04.17	36°23,36	25°22,34	WC	Kameni Islands
POS511-65	19.04.17	36°23,57	25°22,48	WC	Kameni Islands
POS511-65-2	19.04.17	36°23,57	25°22,48	WC	Kameni Islands
POS511-65-3	19.04.17	36°23,57	25°22,48	WC	Kameni Islands
POS511-66	19.04.17	36°24,37	25°22,18	WC	Kameni Islands
POS511-66-2	19.04.17	36°24,37	25°22,18	WC	Kameni Islands
POS511-66-3	19.04.17	36°24,37	25°22,18	WC	Kameni Islands
POS511-67	19.04.17	36°24,60	25°21,92	WC	Kameni Islands
POS511-67-2	19.04.17	36°24,60	25°21,92	WC	Kameni Islands
POS511-68	19.04.17	36°25,19	25°23,64	WC	Kameni Islands
POS511-68-2	19.04.17	36°25,19	25°23,64	WC	Kameni Islands
POS511-69	19.04.17	36°25,53	25°23,79	WC	Kameni Islands
POS511-69-2	19.04.17	36°25,53	25°23,79	WC	Kameni Islands
POS511-70	19.04.17	36°25,34	25°24,23	WC	Kameni Islands
POS511-70-2	19.04.17	36°25,34	25°24,23	WC	Kameni Islands
POS511-71	19.04.17	36°25,24	25°24,31	WC	Kameni Islands
POS511-71-2	19.04.17	36°25,24	25°24,30	WC	Kameni Islands
POS511-72	19.04.17	36°24,21	25°25,25	WC	Kameni Islands
POS511-73	19.04.17	36°24,05	25°25,14	WC	Kameni Islands
POS511-74	19.04-20.04.17	-	-	MB	Mapping south of Christiana
POS511-75	20.04.17	36°24,15	25°25,11	DR	East of Nea Kameni/ mud
POS511-75-2	20.04.17	36°24,15	25°25,11	DR	East of Nea Kameni/ one glass sample
POS511-76	20.04.17	36°23,52	25°24,10	DR	South of Nea Kameni/ no rocks
POS511-76-2	20.04.17	36°23,51	25°24,11	DR	South of Nea Kameni/ no rocks
POS511-77	20.04.17	36°23,59	25°22,13	DR	Southwest of Nea Kameni/ no rocks
POS511-77-2	20.04.17	36°23,60	25°22,14	DR	Southwest of Nea Kameni/ no rocks

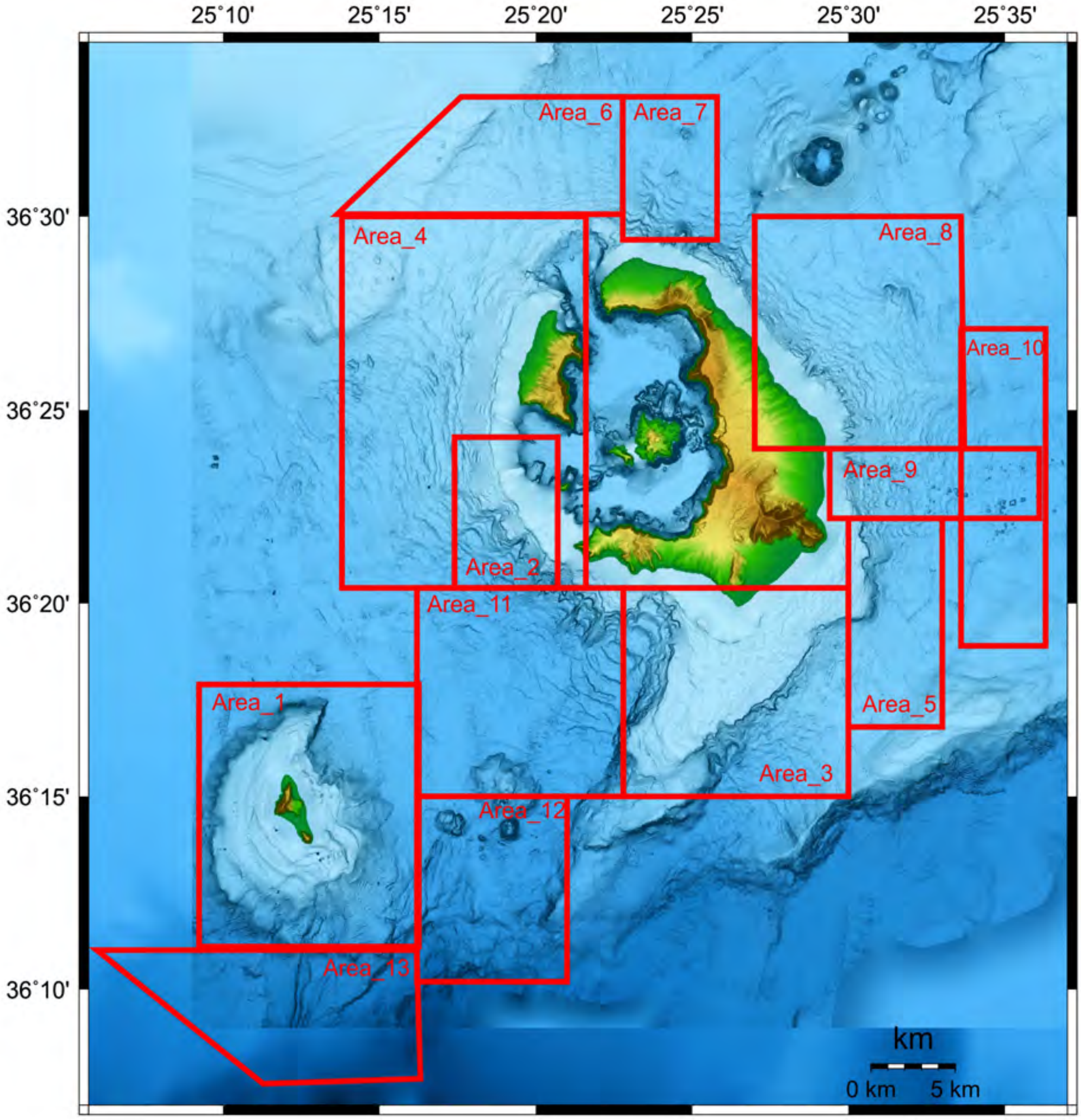
Station No.	Date	Latitude (°N)	Longitude (°E)	Equip-ment	Area surveyed / Samples taken/
POS511-77-3	20.04.17	36°23,59	25°22,14	DR	Southwest of Nea Kameni/ no rocks
POS511-78-1	20.04.17	36°24,82	25°22,14	DR	Northwest of Palea Kameni/some rocks
POS511-78-2	20.04.17	36°24,83	25°22,14	DR	Northwest of Palea Kameni/empty
POS511-79	20.04.17	36°25,71	25°23,92	DR	North of Nea Kameni/ large rock
POS511-80	20.04.17	36°25,69	25°24,36	DR	Northeast of Nea Kameni/ one rock
POS511-81	20.04-21.04.17	-	-	MB	Mapping south of Christiana
POS511-82	21.04.17	36°23,55	25°21,15	ROV	Southern caldera/ only survey-aborted

Table 1: List of sampling stations and scientific activities. Coordinates for ROV tracks and dredge hauls refer to "on bottom" location.

5. Bathymetry (Lampridou, Ioannou)

Bathymetric measurements have been carried out onboard R/V Poseidon with the hull mounted ELAC Nautik's SeaBeam 3050 multibeam echosound system. The installed system is a 50 kHz multibeam with a beamwidth of 1.5° x 2° and a maximum swath width of 140°. The system provides fully motion stabilized multibeam soundings along with Heave Roll and Pitch data. The maximum operation water depth of the system is about 3000 meters, depending on sea state conditions.

Swath mapping during POS 511 has been conducted on daily basis during the nights, around Santorini and Christiana islands (Fig. 4). The data were acquired using the hydrographic software HYPACK (as half hour ".HSX" files) and pre-processed with an open source MB-SYSTEM. Further processing will take place at the University of Athens (Danai Lampridou and Theodora Ioannou). The main aim is to combine the new dataset (obtained during POS511) with existing data sets (e.g. Nomikou et al., 2012a) in order to increase the resolution of the Digital Terrain Model and produce a more detailed bathymetric map. An example of an already resulting improved map quality is given in Fig. 5.



Legend

Area	Date	Area	Date
1	01.04–02.04.17	9	14.04.17
2	03.04.17	10	15.04.17
3	04.04–05.04.17	11	16.04.17
4	06.04–07.04–08.04.17	12	17.04–18.04.17
5	09.04.17	13	19.04–20.04.17
6	10.04–11.04–12.04.17		
7	12.04.17		
8	13.04.17		

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Fig. 4: Location of mapping areas of Exp. 511. Map based on Hooft et al. (2017-in press) and Nomikou et al. (2013a; 2016b).

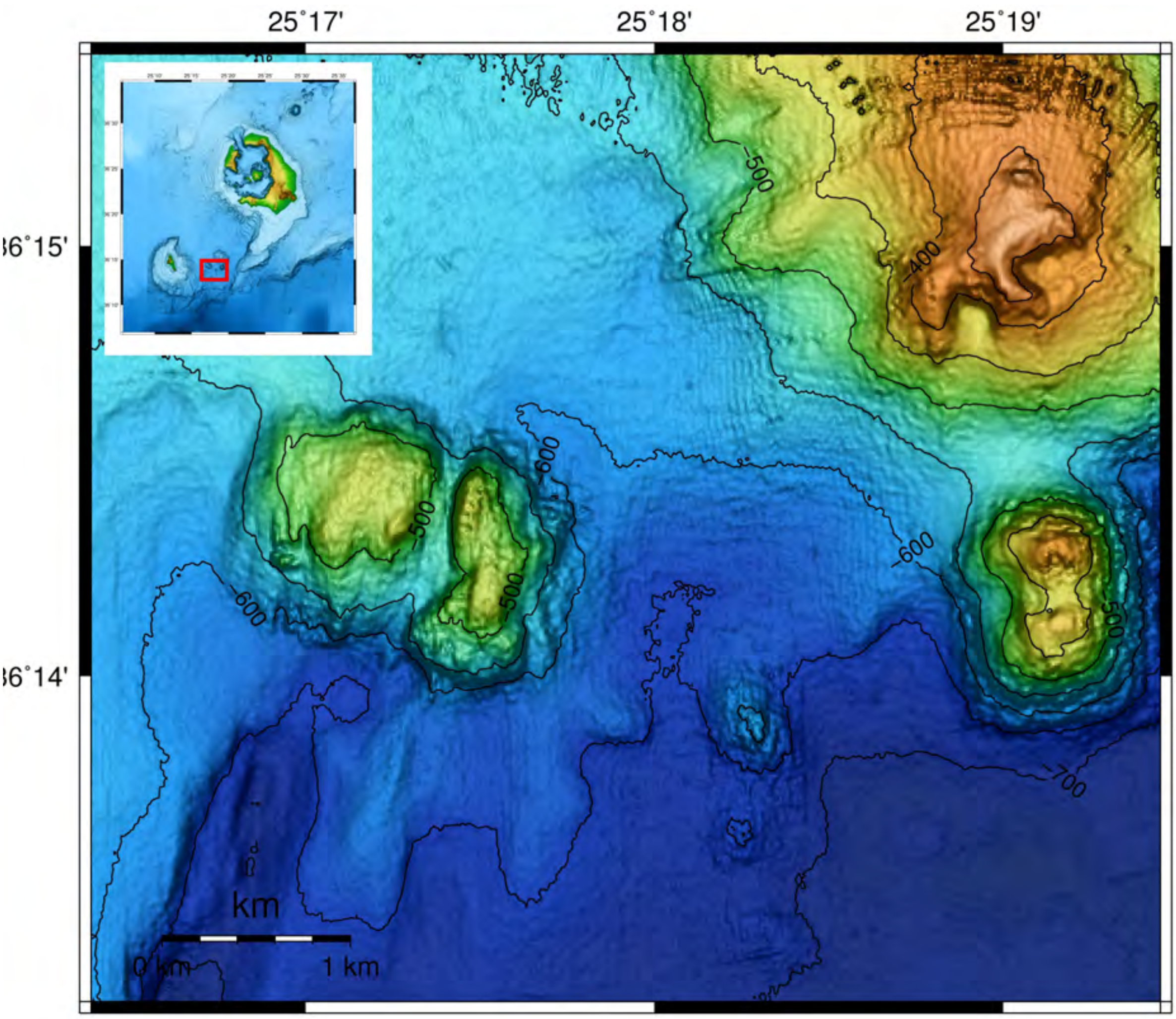

Fig. 5: Highly detailed map (ten meters grid) using the newly acquired POS 511 data for the area of the three seamounts to the east of the Christiana Islands. Note the now visible channel splitting the western seamount in comparison to its previous appearance in Fig. 2. (Map processed on board by Danai Lampridou and Theodora Ioannou).

6. ROV Deployments (Pieper, Cuno, Meier, Matthiessen, Suck)

6.1 Technical Overview

The remotely operated vehicle (ROV) PHOCA used during this expedition is a 3000 m rated deep diving platform manufactured by SubAtlantic FET, Aberdeen, Scotland. It is based on commercially available ROVs, but customized to scientific demands, e.g. being truly mobile. ROV PHOCA has previously been operated from the German research vessels POSEIDON, SONNE and ALKOR. During POS511, a midwater winch with a steel armored fiber optic cable was used with a maximum length of 2700 m and a 19 mm diameter. The deck's setup during launch is shown in Fig. 6.

Fig. 6: ROV PHOCA being launched from RV Poseidon in the caldera of Santorini (off Cape Simandiri, Therasia Island). Foto: J. Geldmacher, GEOMAR

The vehicle carries various cameras: 1 HDTV Bullshark (which was set up to record permanently), 2 color zoom video cameras (OE14-366) mounted on pan and tilt units, 2 black and white video cameras (OE15-108) and a digital stills camera. Lighting for the video cameras is provided by 4 MultiSeaLite Matrix LEDs (250 W) and 4 dimmable 250 W Deep MultiSeaLite Halogen lights.

Navigation was provided by one ORE Trackpoint USBL Transponder (Edgetech) communicating with a transceiver deployed through the ship's moonpool, with a CDL TOGS fiberoptics Gyro and an RD Instruments 1200 Doppler Velocity Log. The vehicle also carried a FastCAT CTD SBE 49 manufactured by SeaBird. Real time observational logs were kept using OFOS (Ocean Floor Observation System) by a scientist in the laboratory.

ROV PHOCA is based at GEOMAR, Helmholtz Centre for Marine Sciences Kiel, Germany. More details on the ROV system are available at: http://www.geomar /PHOCA.

6.2 ROV tasks during POS511

During this cruise, one main objective was photogrammetry of the sea floor, i.e. of steep rocky walls. For these deployments, a DeepSurveyCam (Fig. 7) was mounted on the starboard drawer so that the direction of vision (horizontal to vertical) could be changed by moving the drawer. The DeepSurveyCam flash was provided by 2 high power LED strobe arrays, held in the two manipulator ORION arms of the vehicle and therefore adaptable to lighting demands at the seafloor.

The second task was to sample volcanic rocks from defined locations (stratigraphically controlled sampling). For this purpose, both drawer boxes were adapted with variable compartments in order to fit different sizes of rocks (Fig. 8). In addition to the ORION manipulators, a chisel was used to break off pieces of rocks (Figs. 9a-d).

Fig. 7: Photogrammetry setup with DeepSurveyCam on starboard drawer and two flashlight arrays in the manipulator arms. Photo: ROV-Team, GEOMAR

Fig. 8: Rock Sampling Setup: compartmented drawers after a successful dive. Photo: ROV-Team, GEOMAR

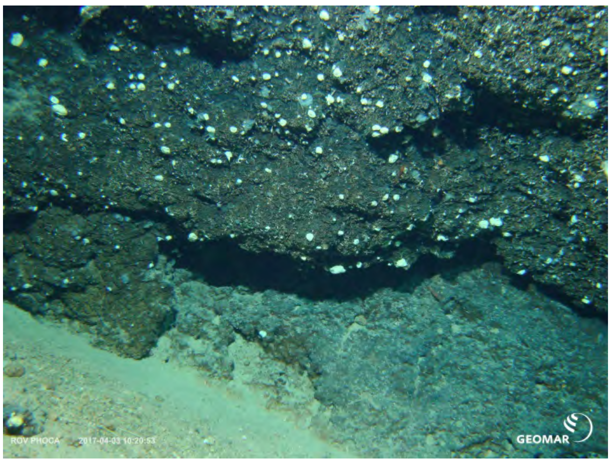

Fig. 9a: Underwater landscape off Christiana Island, south of Santorini (Dive ROV-7-02).

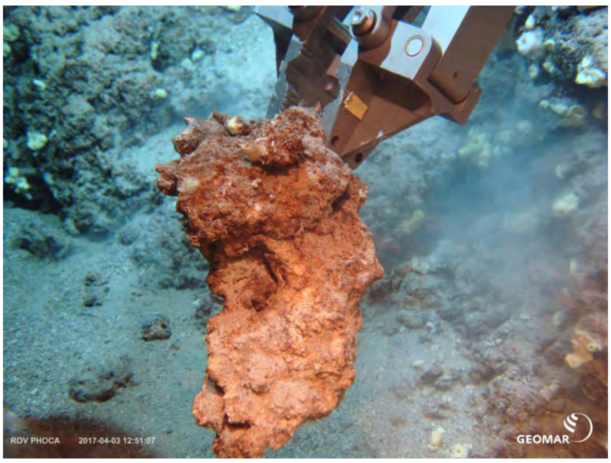

Fig. 9b: ORION taking a sample off Christiana (Dive ROV-7-02).

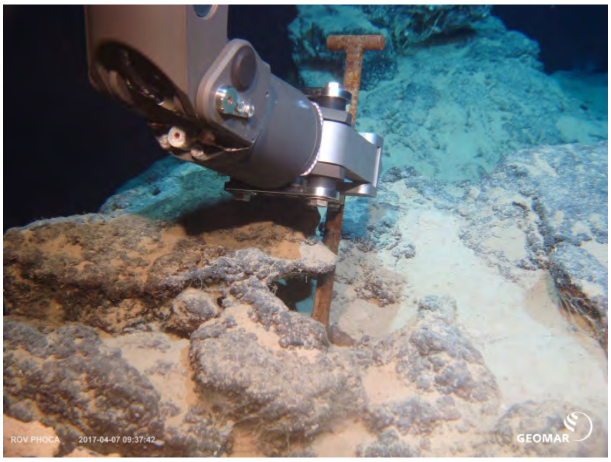

Fig. 9c: Left ORION is using the chisel to break off some massive rocks off Santorini's southern platform slope (Dive ROV-21-06).

Fig. 9d: Underwater landscape in the Santorini caldera (Dive ROV-34-11).

During cruise POS 511, 21 scientific dives were conducted (Tab. 2). Maximum bottom time was 08:24 hours accumulating to approx. 64 hours (total dive time approx. 76 hours). Two dives had to be abandoned due to a burst hose and malfunctioning thrusters, respectively. Floating lost fishing gear posed some kind of a problem as during dive ROV-56-17 a net was trapped in the float pack and brought up to the surface by accident, while during dive ROV-59-18, 2 lines actually trapped the first float pack and it took about an hour to free the ROV. During dive ROV-21, a dead vehicle recovery was necessary due to burnt fuses in the transformer box. A more detailed description of individual deployments is given in chapter 4.1.

The ROV Team would like to thank Captain Guenther and his crew for cooperation.

Station Number POS511	Dive No.	Date (UTC)	Time Start (UTC)	At Bottom (UTC)	Off Bottom (UTC)	Time End (surface) (UTC)	Location	Depth (m)	ROV Bottom Time	
Test	75	31.03.2017								
05ROV01	76	02.04.2017	12:28	12:57	14:42	14:57	Christiana East	450	01:45	Photogrammetry
07ROV02	77	03.04.2017	06:55	07:19	13:02	13:18	Christiana East	450-200	05:43	Rock sampling
09ROV03	78	04.04.2017	06:44	07:03	11:09	11:21	Christiana NE	400-200	04:06	Photogrammetry
17ROV04	79	06.04.2017	05:53	06:13	07:30	07:43	Santorini S TS1	530-200	01:17	Photogrammetry
18ROV05	80	06.04.2017	09:15	09:32	14:15	14:24	Santorini S TS2	400-150	04:43	Photogrammetry
21ROV06	81	07.04.2017	05:43	06:04	14:28	14:48	Santorini S TS1	570-205	08:24	Rock sampling
27ROV07	82	10.04.2017	06:26	06:47	09:04	09:22	SC I West	195-20	02:17	Photogrammetry
28ROV08	83	10.04.2017	11:12	11:29	13:30	13:43	SC I East	345-230	02:01	Photogrammetry
30ROV09	84	11.04.2017	06:33	06:46	07:32	07:44	SC II South	270	00:46	Hose burst
33ROV10	85	12.04.2017	06:19	06:32	09:45	09:59	SC II South	275-225	03:13	Rock sampling
34ROV11	86	12.04.2017	10:28	10:41	14:02	14:14	SC II South	210-140	03:21	Rock sampling
36ROV12	87	13.04.2017	06:35	06:50	10:15	10:27	SC III Southwest	260-150	03:25	Rock sampling
37ROV13	88	13.04.2017	11:17	11:32	13:41	13:54	SC III Southwest	310-210	02:09	Rock sampling
40ROV14	89	14.04.2017	06:15	06:31	10:10	10:21	SC IV North	340-135	03:39	Rock sampling
41ROV15	90	14.04.2017	11:29	11:45	12:11	12:24	SC IV North	330-300	00:26	Rock Sampling; Thrusters malfunctioning
56ROV16	91	16.04.2017	05:58	06:21	09:55	10:11	Santorini S TS 1	545 4x	03:34	Rock sampling
57ROV17	92	16.04.2017	11:24	11:45	14:11	14:36	Santorini S TS 2	3xx-275	02:26	Rock sampling / Net on float pack
59ROV18	93	17.04.2017	05:35	05:54	09:07	09:29	Seamount TS 1	515-??	03:13	Rock sampling / 2 lines entangled in floats
60ROV19	94	17.04.2017	10:38	11:00	13:54	14:08	Seamount TS 2 Crater	4xx - 3xx	02:54	Rock sampling
62ROV20	95	18.04.2017	05:44	05:58	09:28	09:34	SC East	235-85	03:30	Rock sampling
63ROV21	96	18.04.2017	11:47	11:59	13:35	14:09	SC Central	200	01:36	Rock sampling / Dead vehicle recovery
Total: 21 scientific dives									**64:28**	

Table 2: ROV station list. Station number includes consecutive count of ROV dives during cruise POS 511 (SC = Santorini Caldera; TS = Transect).

7. Photogrammetric Surveys (Kwasnitschka)

For conducting photogrammetric surveys of the seafloor for later structural, volcanological and habitat studies (in addition to seafloor reflectivity studies) a high-resolution SLR stills camera was mounted on ROV PHOCA (Figure 10). A similar setup as during POS 502 (NKR-Cycles) was used, yet this time the camera could be tilted to face the seafloor and on-board post processing infrastructure was provided.

Fig. 10: ROV Phoca with the DeepSurveyCam mounted on the front porch (Photo: Kwasnitschka, GEOMAR).

A CANON Eos 6D SLR of 20MP resolution with a 15mm fisheye lens (CANON 8-15mm, f4.5 zoom) was employed as part of the DeepSurveyCam package described in Kwasnitscka et al. (2016). This system was developed for the AUV Abyss and uses a high power LED strobe. Of the three strobe arrays normally employed only two were carried on either manipulator arm of the ROV (while the third remained unused). Thus, it was possible to precisely adapt the illumination pattern to the requirements of the terrain. The camera was mounted on the starboard front porch on a hydraulic tilt unit, oriented in landscape mode relative to the direction of travel. Camera orientation was logged inside the camera housing and will be fused with other navigation information.

Station (Dive no.)	Frames	Format
ROV-5 (01)	2569	jpg
ROV-9 (03)	5693	jpg
ROV-17 (04)	3528	jpg
ROV-18 (05)	9827	jpg

Table 3: Statistics of photogrammetric coverage.

A total of six surveys were conducted. Table 3 gives the statistics of the first for dives. Visibility varied between sites due to varying particulate matter in the water column, so an optimum altitude of four meters was aimed for. Useful results were gathered at up to 6 m altitude while the continuity of the reconstruction could still be maintained at 8 m altitude. At an across track field of view of about 160°, this resulted in a useful track width of about 15m limited by scattering and absorption. Minimum altitude was around 2 m dictated by the amount of overlap between each image (Fig. 11).

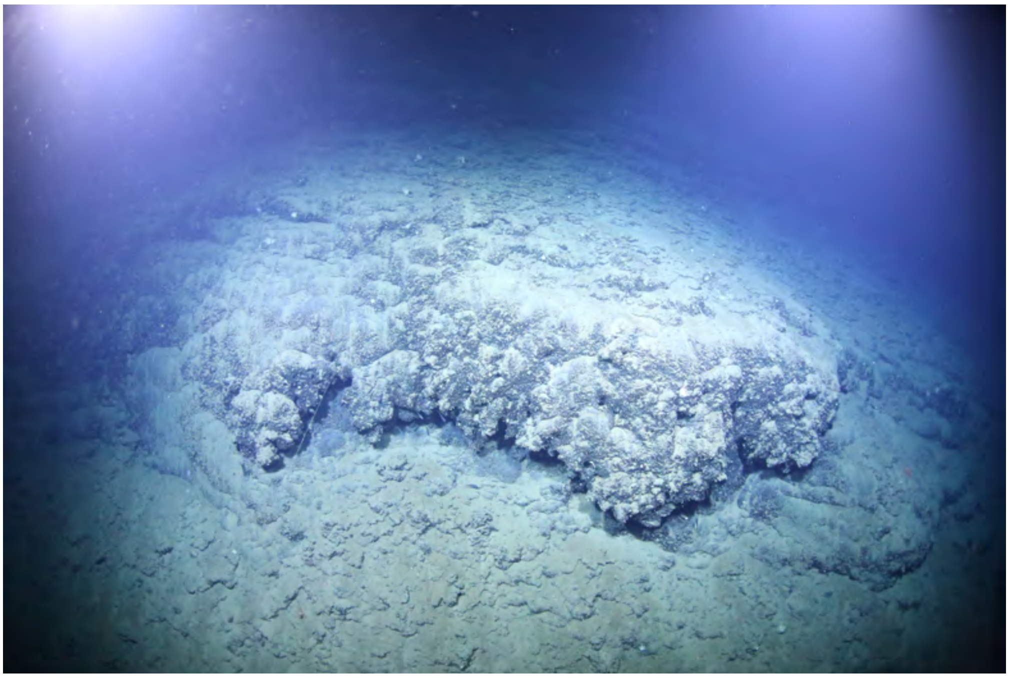

Fig.11: A frame from dive ROV-9 (03), foreground c. 4 m away, background c. 10 m away. Photo: ROV-Team, GEOMAR

After each dive, processing involved the correlation and cross-referencing of USBL and DVL navigation records, which then served as a first order pose estimation to initialize the photogrammetric reconstruction and, together with multibeam maps, form the basis for georeferencing of the reconstructions. Photogrammetric reconstructions are done using the Agisoft Photoscan Pro software as detailed in Kwasnitschka et al. (2012). Employing a powerful workstation (HPZ840, 64GB RAM), a first order reconstruction of dive results could be obtained by the next morning, available for sampling dives. Due to some workflow changes in between POS 502 and POS 511, which needed to be accounted for in the scripts employed, overnight processing was only really effective in the third week of the cruise, but was demonstrated successfully (Fig. 12).

Fig. 12: Profile 1 of ROV-9 (03) shows the volcaniclastic sequence at the northeastern slope of Kristianna Island. The vertical extent of this transect is 172m.

7. Dredging

Generally, the most effective and cost-efficient method to obtain hard rock samples from the sea floor is dredging. During POS 511 two different kinds of dredges were used: chain sack dredge and barrel dredge, with the latter being smaller and slightly lighter. Figure 13 shows a chain sack dredge that weighs almost 500 kg. The bottom is open with a chain sack attached. The dredge is lowered on a wire (using deep sea winch W3) and hauled up the slopes of volcanic structures following the assumption that steep slopes are largely free of sediment cover or at least partly expose rock surfaces. Samples hauled into the dredge during the dredging process will usually fall into the chain sack where they get trapped. Unfortunately, the CSK volcanic area turned out to be extremely difficult to sample by dredging because many dredges returned either full of mud or got stuck on the ground (see 4.1 Daily Narrative for details).

Fig. 13: A returning chain sack dredge (DR-13) full of heavy mud hanging off the portside deck of the POSEIDON (Photo: J. Geldmacher).

8. Wax Corer

The wax corer is used to collect volcanic glass fragments from the surface of exposed (young) lava flows. It is made up of a steel tube holding at least 200 kg of metal weights and a flat head (crusher plate) containing 7 holders for wax filled cups (Fig. 14). The device is launched over the side of the POSEIDON on a wire (using winch W3) and lowered until it crushes on the sea floor. Fragments of rock (volcanic glass rims) that break off of the lava flow on impact are trapped in wax-tipped cups mounted on the crusher plate. Back on shore, the wax is melted in the lab to liberate the glass particles for microprobe analysis. A prerequisite for successful sampling is the existence of glassy lava surfaces exposed on the seafloor and uncovered by sediment (meaning *young* flows). At the CSK volcanic complex such conditions are believed to exists on the slopes of the Kameni islands which were formed by relatively young lava flows within the last 2000 years with the most recent eruption occurring in 1950 (e.g. Nomikou et al., 2014a).

Fig. 14: Master Student Phillip Kosbü (University of Kiel) replacing the wax filled cups mounted around the crusher plate of the wax corer during Exp. POS511 (Photo: J. Geldmacher).

While the propellers of the ROV received urgently needed maintenance on April 15, we deployed the wax corer for the first time during this expedition around the Kameni Islands in the center of the caldera. While previous work focused on studying the sub-aerial exposed Kameni lavas, little attempt has been made so far to sample the submarine extension of the islands. By encircling the two islands and taking lava (glass) samples with the wax corer from bathymetrically clearly distinct lava flows/lobes we hope to be able to correlate the submarine structures with subaerially exposed eruptive centers of known age. In total we have deployed the wax corer 22 times at 12 different locations around the two islands (Fig. 3).

9. CTD and water sampling

Water samples were taken during POS511 using the ships own CTD-system (SeaBird, SBE) equipped with twelve 10 liter bottles on a SeaBird Rosette SBE-31 carousel (Fig. 15). While taking samples from 100, 75, 50, 25, 10 and 2 m depths, temperature, salinity and pressure measurements were automatically conducted by the instrument. The aim of the sampling was to collect coccolithophore plankton, to study its species distribution and morphology in the area of Santorini submarine volcanoes, in order to investigate potential acidification effects. Coccolithophores are among the dominant primary producers, presenting a high number of species (> 100) in the oligotrophic eastern Mediterranean Sea. Coccolithophores of the photic zone in the Aegean Sea indicate a close relationship between coccosphere densities and surface water circulation, with sea temperature gradient and nutrient availability affecting species composition. The sensitivity of calcification processes to ocean acidification makes coccolithophores one of the first organisms that will be affected by increasing CO_2 levels in the ocean. Submarine volcanoes, such as Kolumbo, are well known to emit significant amounts of CO2, thus locally contributing to the production of this greenhouse gas.

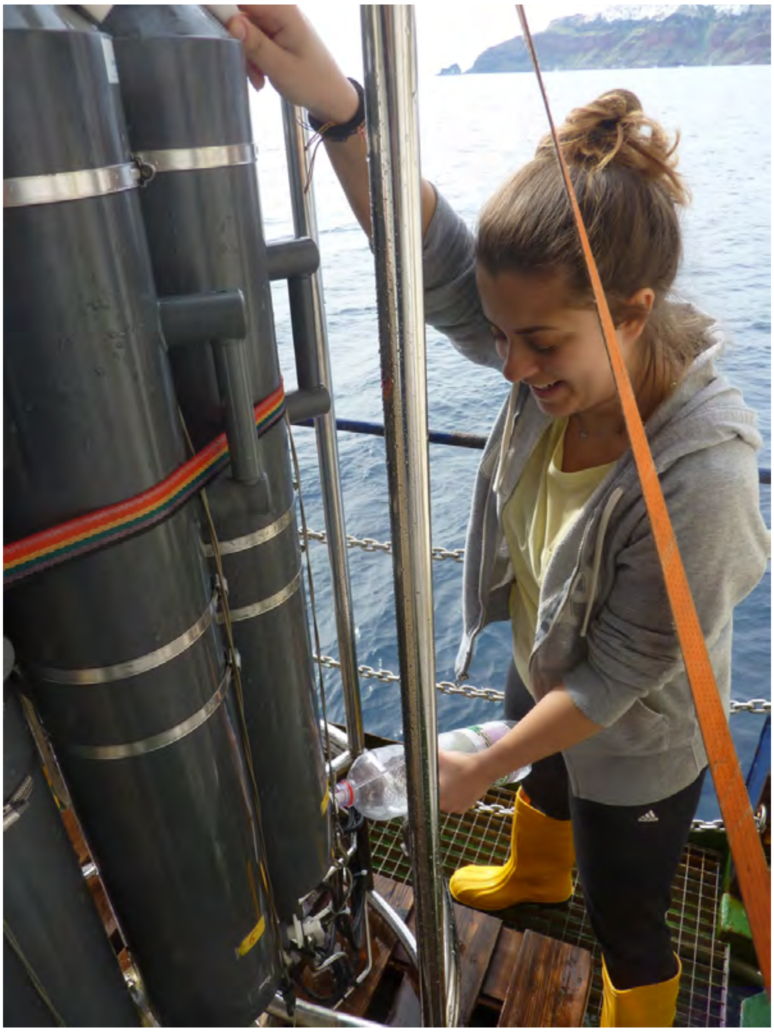

Fig. 15: Master student Theodora Ioannou (University of Athens) taking water samples from the SeaBird Rosette carousel of the CTD in the caldera of Santorin. (Photo: J. Geldmacher)

For coccolithophore sampling during POS511, two liters of seawater per sample were filtered on Whatman cellulose nitrate filters (47 mm diameter, 0.45 μm pore size), using a Whatman membrane filter holder and vacuum filtration system; particular caution was taken for even distribution of the filtered material. Salt was removed by washing the filters with 2 ml of mineral water. The filters were oven dried and stored in plastic Petri dishes. The investigation of the coccolithophore samples will take part at the university of Athens (Prof. Maria Triantaphyllou).

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